A scaling law of interstellar depletions as a tool for abundance studies of Damped Ly α Systems

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Abstract. An analytical expression is presented that allows dust depletions to be estimated in different types of interstellar environments, including Damped Lyα systems. The expression is a scaling law of a reference depletion pattern and takes into account the possibility that the dust chemical composition may vary as a function of the dust-to-metals ratio and of the intrinsic abundances of the medium. Preliminary tests and applications of the proposed scaling law are briefly reported.

1 Introduction

The presence of dust can severely affect the measurement of elemental abundances in Damped Ly α systems (DLAs) [4, 5, 1]. Dust depletions in DLAs resemble those observed in the warm gas of the disk or halo of the Milky Way [3, 2]. However, disentangling the dust depletion effects from the intrinsic abundance patterns of DLAs, which may differ from the solar one, is a difficult task. A method for estimating depletions in DLAs with minimal assumptions on their intrinsic abundances was presented in [7]. In that work the dust in DLAs was assumed to have the same composition as the dust in Galactic warm gas. The dust-to-gas ratio of individual DLAs was then estimated from the observed overabundances of the Zn/Fe ratio, assuming that the intrinsic Zn/Fe ratio is solar. While successful in estimating dust-corrected abundance ratios in DLAs, the method [7] has two limitations: (1) the dust composition, taken to be constant, may instead vary in different systems; (2) the Zn/Fe ratio may show some deviations from the solar value [6]. Here we present a general scaling law of interstellar depletions that can avoid the above limitations once implemented in the method [7]. A full presentation of this work will be given in a separate paper.

2 The scaling law

To derive the scaling law we first define the fraction in dust of an element X as $f_{\rm X} \equiv N_{\rm X,dust}/N_{\rm X,(gas+dust)}$. By choosing an element Y as a reference for measuring the dust content and the relative abundances, we obtain the expression $f_{\rm X} = r\, a_{\rm X}^{-1}\, p_{\rm X}$, where $r \equiv f_{\rm Y}$ is the *dust-to-metals ratio*, $a_{\rm X} \equiv ({\rm X/Y})_{\rm (gas+dust)}$ the relative abundance in the medium, and $p_{\rm X} \equiv ({\rm X/Y})_{\rm dust}$ the relative abundance in the dust. We then assume that the chemical composition of the dust

is a function of r and $a_{\rm X}$, i.e. $p_{\rm X} = p_{\rm X}(r, a_{\rm X})$. Therefore $f_{\rm X} = f_{\rm X}(r, a_{\rm X})$ and from logarithmic differentiation we obtain

$$\frac{df_{\rm X}}{f_{\rm X}} = (1+\eta_{\rm X})\ \frac{dr}{r} + (\varepsilon_{\rm X} - 1)\ \frac{da_{\rm X}}{a_{\rm X}}\ , \qquad (1)$$

where $\eta_{\rm X} \equiv \frac{r}{p_{\rm X}} \frac{\partial p_{\rm X}}{\partial r}$ and $\varepsilon_{\rm X} \equiv \frac{a_{\rm X}}{p_{\rm X}}\ \frac{\partial p_{\rm X}}{\partial a_{\rm X}}$. At this point we integrate Eq. (1) assuming $\eta_{\rm X}$ and $\varepsilon_{\rm X}$ to be constant along the integration path running from $(f_{{\rm X},i},\ r_i,\ a_{{\rm X},i})$, representative of a reference interstellar environment i of solar chemical composition, to $(f_{{\rm X},j},\ r_j,\ a_{{\rm X},j})$, representative of an arbitrary interstellar environment j. From this integration we derive the scaling law

$$f_{{\rm X},j} = \left(\frac{r_j}{r_i}\right)^{(1+\eta_{\rm X})}\ 10^{(\varepsilon_{\rm X}-1)\left[\frac{\rm X}{\rm Y}\right]_j}\ f_{{\rm X},i}\ , \qquad (2)$$

where $[{\rm X/Y}]_j \equiv \log({\rm X/Y})_j - \log({\rm X/Y})_\odot$. Eq. (2) is a generalization of Eq.(11) given in [7]. The fractions in dust $f_{\rm X}$ are directly related to the elemental depletions measured in interstellar studies. Therefore the validity of Eq. (2) can be tested observationally. The dependence of $f_{{\rm X},j}$ on (r_j/r_i) can be probed in the Milky-Way ISM, where $[{\rm X/Y}]_j = 0$ and the depletions are known for many lines of sight. From this type of investigation we find that all the typical depletion patterns of the Milky Way can be successfully reproduced with Eq. (2) by only varying (r_j/r_i) [8]. To probe the dependence of $f_{{\rm X},j}$ on $[{\rm X/Y}]_j$ one needs to measure interstellar depletions in galaxies of known chemical composition, such as the Magellanic Clouds. From a study of SMC lines of sight we find evidence that these type of observations can indeed be used to probe and calibrate Eq. (2) (work in preparation). Once calibrated with Galactic and extragalactic interstellar observations, the scaling law (2) can be implemented in the method [7] and applied for correcting abundances of DLAs for dust depletion effects. The intrinsic Zn/Fe ratio in DLAs can be treated as a free parameter since deviations of Zn/Fe from the solar value are considered in a self-consistent way in Eq. (2). Preliminary results of application of this revised procedure to DLAs indicate that the [Si/Fe] ratio is, on the average, lower than in Milky Way stars of similar metallicity [8].

References

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